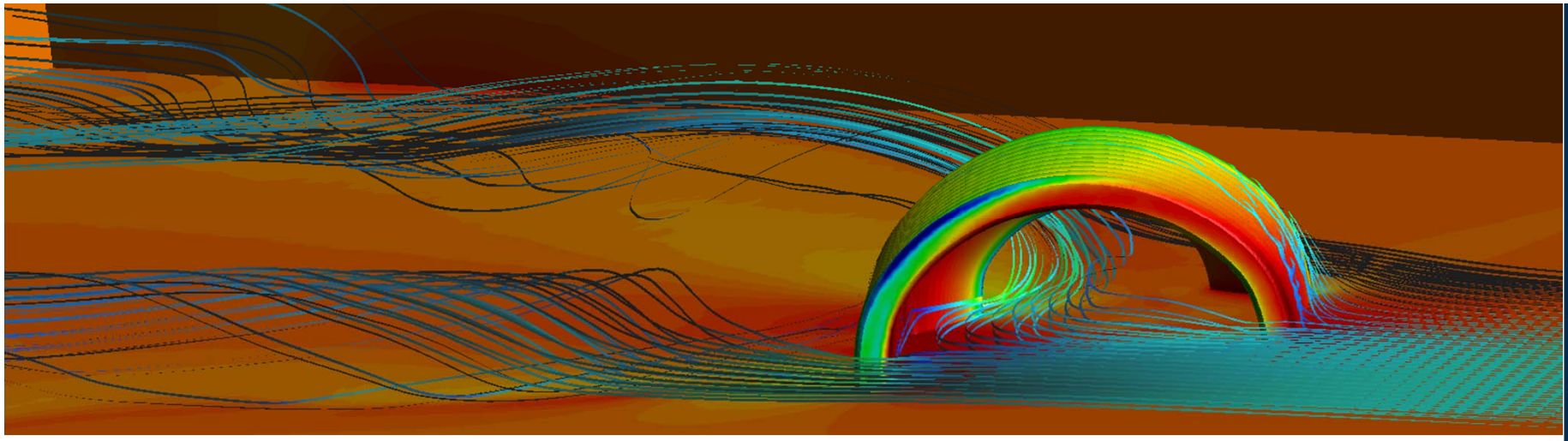


FSI ANALYSIS OF LIGHTWEIGHT STRUCTURES

TOWARDS A VIRTUAL WIND TUNNEL

A. Larese, R. Rossi, R. Wüchner,
H. Al Sofi, P. Ryzhakov and E. Oñate

uLites
Grant No. 314891

International Center for Numerical Methods in Engineering
CIMNE

Outline

- MOTIVATION and OBJECTIVES
- THE VIRTUAL WIND TUNNEL
  - THE CFD AND STRUCTURAL CODES
  - THE GRAPHICAL ENVIRONMENT
  - MAIN ISSUES
- FLOWCHART
- EXAMPLES
- CONCLUSIONS

uLites project

Ultra lightweight structures with integrated photovoltaic solar cells: design, analysis, testing and application to an emergency shelter prototype FP7-SME-2012-314891

MAIN RESULTS OF THE PROJECT:

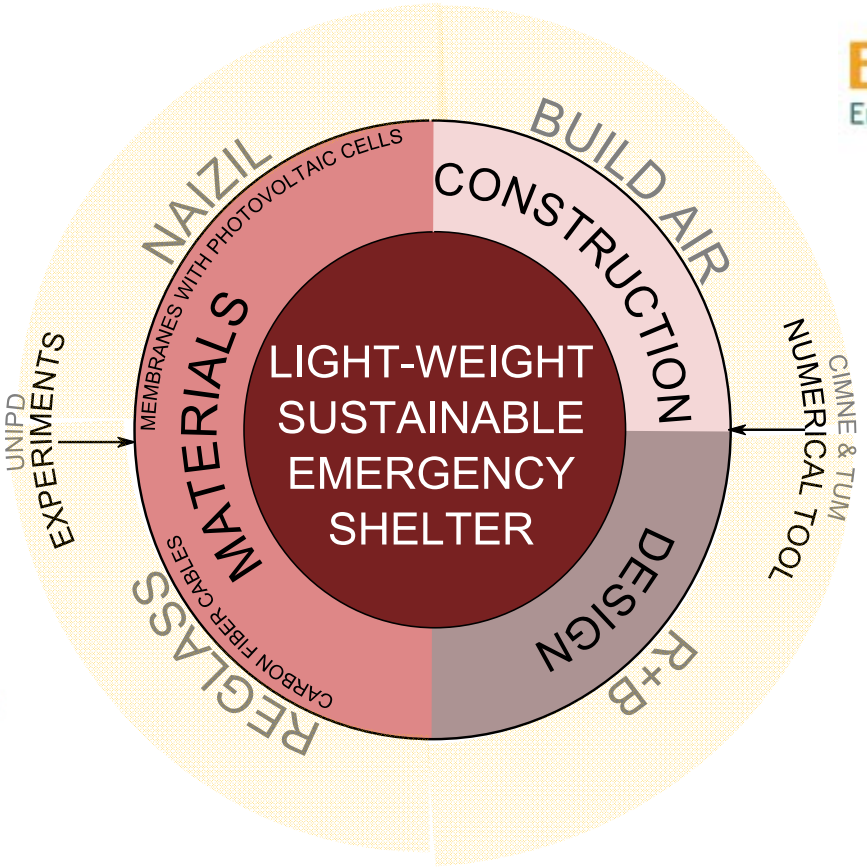
1. Design and construction of a **LIGHT-WEIGHT SUSTAINABLE EMERGENCY SHELTER** with **innovative materials** and integrated **flexible photovoltaic modules**

   - Innovative material (photovoltaic membranes, ultra-flexible carbon fiber cables)
   - Creation of a **VIRTUAL WIND TUNNEL**

uLites project

INDUSTRIAL PARTNERS

naizil S.p.A. TESSUTI SPALMATI



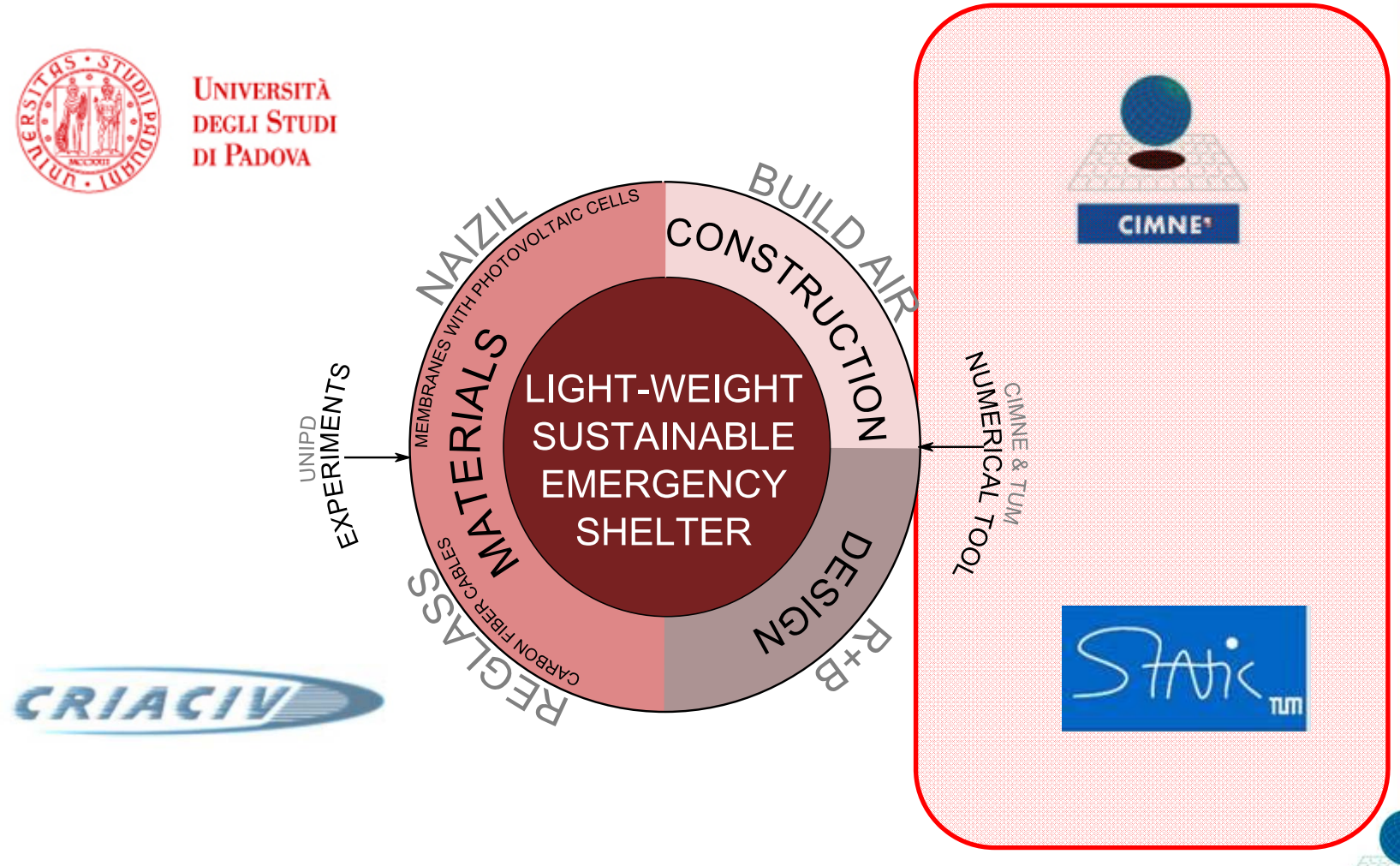
Build air
Engineering + Architecture

reglass

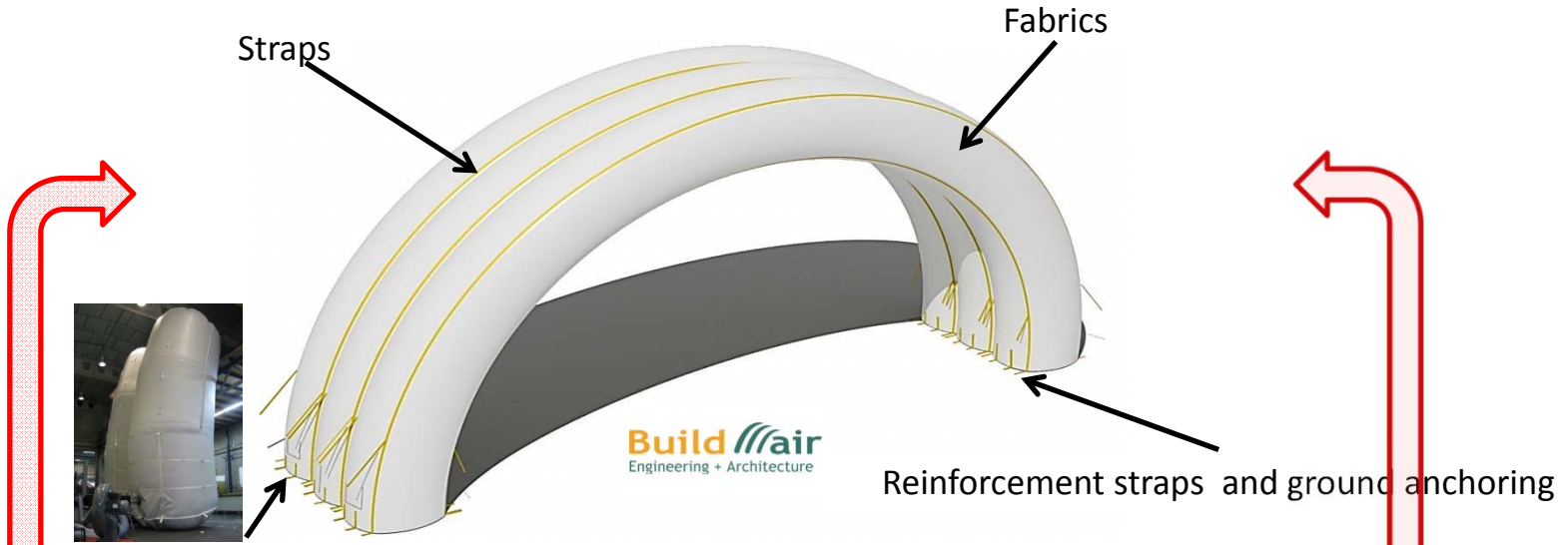
SL-RASCH GMBH

MOTIVATION

uLites project



ULITES PROTOTYPE: ingredients



naizil TESSUTI SPALMATI

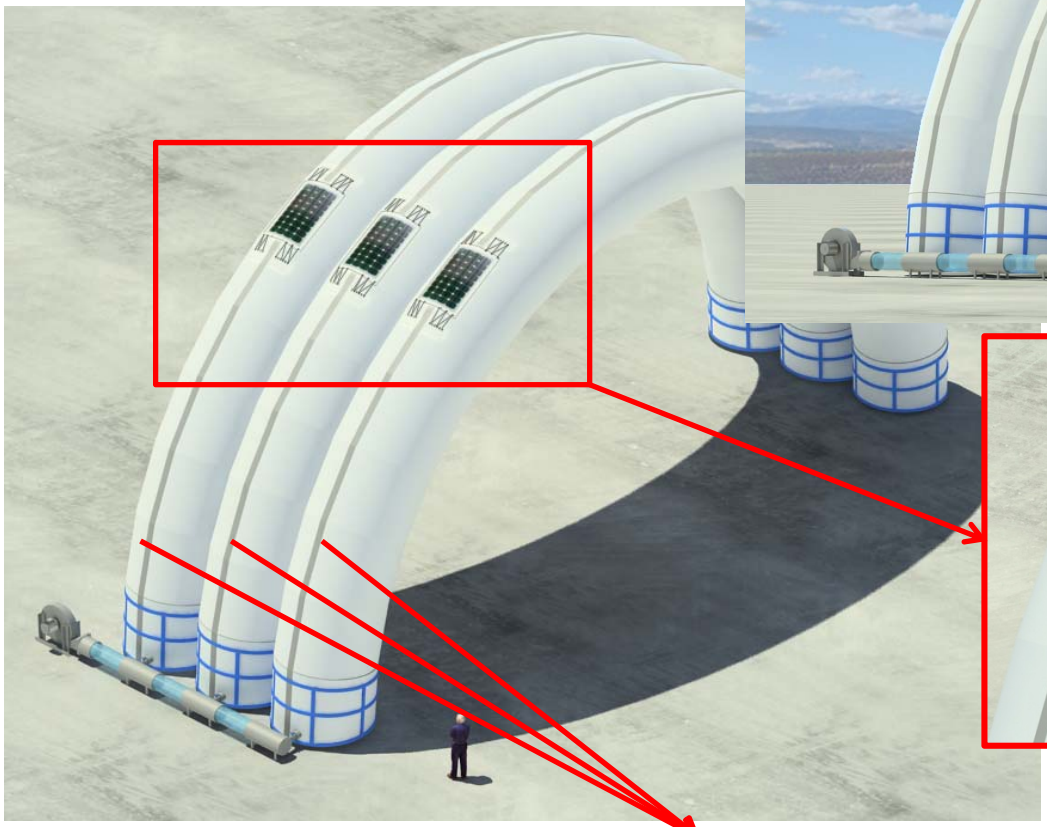
FLEXIBLE PHOTOVOLTAIC MODULES

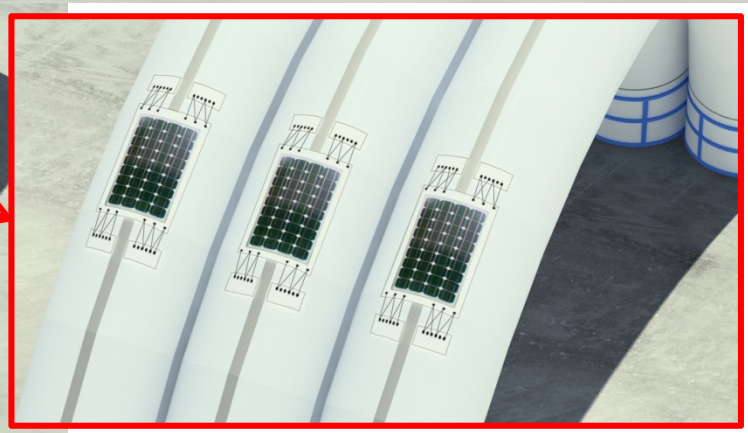
FLEXIBLE CARBON FIBER STRIPES
Curvature radius <2cm

Reglass

MOTIVATION

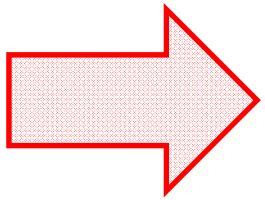
ULITES PROTOTYPE





DESIGN OF LIGHT-WEIGHT STRUCTURES

EXTREMELY **LIGHT**
STRUCTURAL
WEIGHT



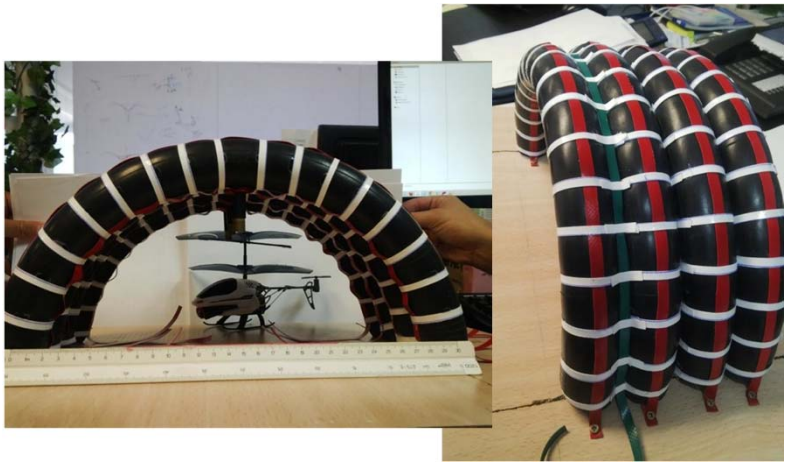
STRUCTURAL BEHAVIOUR
is determined by the
WIND ACTION

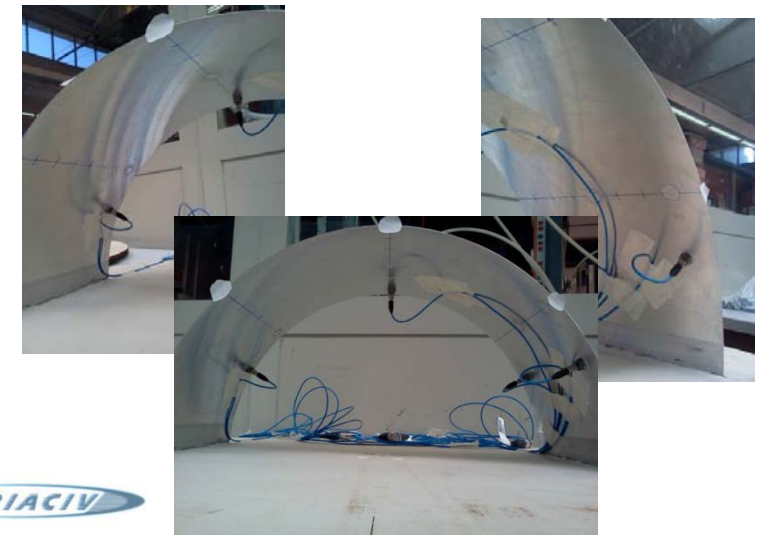
HOW TO CALCULATE AND DIMENSIONING
THIS STRUCTURE?

DESIGN OF LIGHT-WEIGHT STRUCTURES

PHYSICAL PROTOTYPES
EXPERIMENTAL CAMPAIGN

WIND TUNNEL TESTS





- **MASS/MATERIAL SCALING** can not be performed on reduced models. Impossible to reproduce relevant scaling in Wind Tunnels, thus largely invalidating wind tunnel results

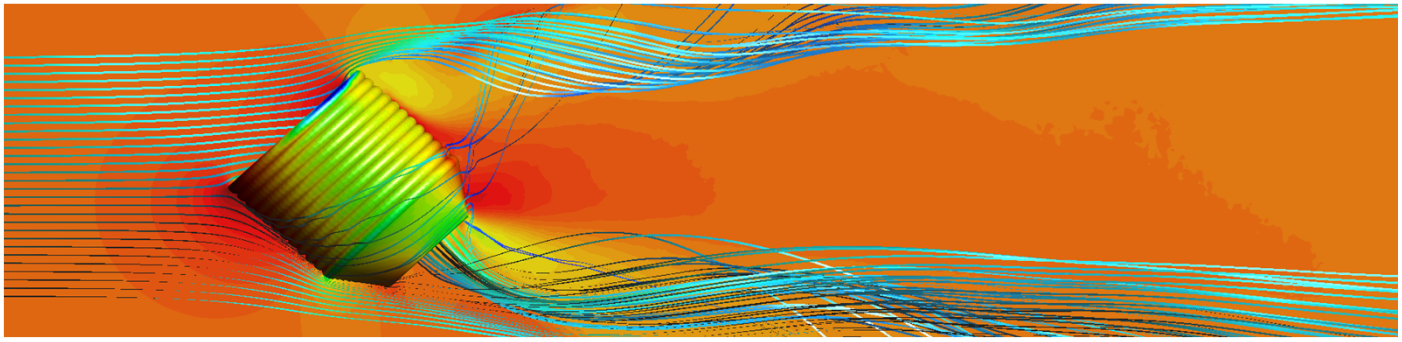
- Unfortunately the **structural deformability is very high**, giving rise to LOW NATURAL PERIODS, making **DYNAMIC EXCITATION** a major concern.

DESIGN OF LIGHT-WEIGHT STRUCTURES

NUMERICAL WIND TUNNEL TESTS

Virtual Wind Tunnel

- Possible the representation in scale 1:1 of the real structure (materials and geometry) and the appropriate boundary conditions
- Money saving
- Time saving
- A computational challenge!



THE VIRTUAL WIND TUNNEL (VWT)

STRUCTURAL SOLVER

Lehrstuhl für Statik, Chair of Structural Analysis at TUM

CFD SOLVER

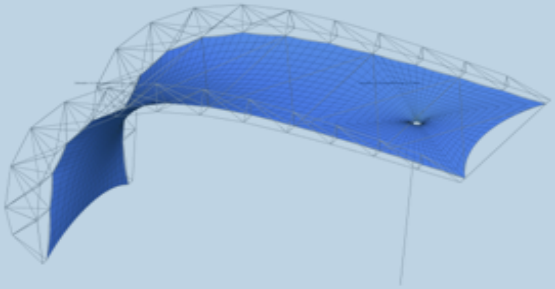
INTERNATIONAL CENTER FOR NUMERICAL MEHODS IN ENGINEERING (CIMNE)

Centre Internacional de Mètodes Numèrics en Enginyeria

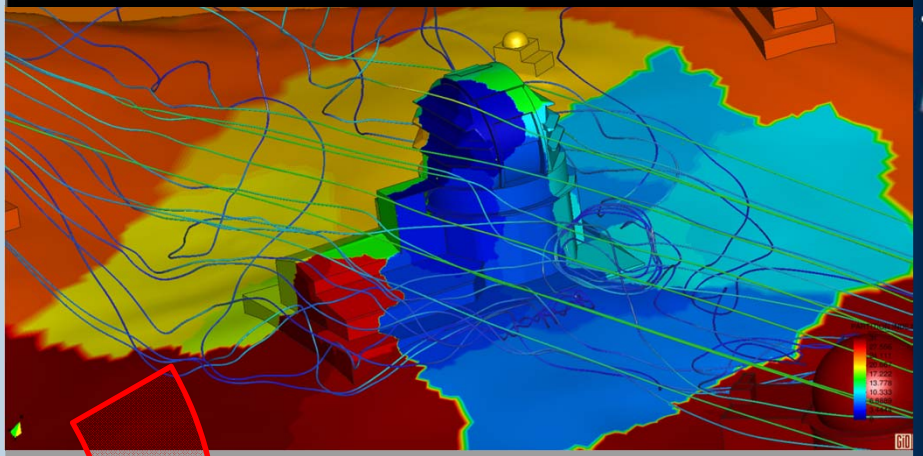
KRATOS MULTI-PHYSICS

THE VIRTUAL WIND TUNNEL (VWT)

Structure Solver
Carat++



KRATOS MULTI-PHYSICS



CIMNE
Centre Internacional de Mètodes Numèrics en Enginyeria

STRUCTURAL SOLVER

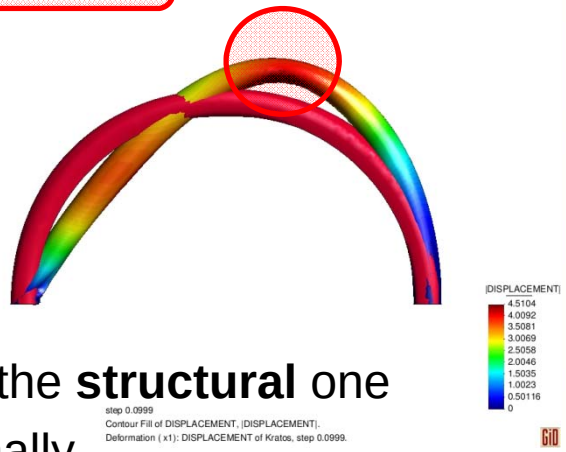
CFD SOLVER

EMBEDDED APPROACH

HOW TO TREAT THE STRUCTURE IN THE CFD ANALYSIS?

~~BODY FITTED~~ OR EMBEDDED APPROACH

More accurate
But
Typically failing when wrinkles appears



- User defines **SEPARATELY** the **fluid** domain and the **structural** one
- The CFD solver "intersects" the two domains internally.
- CFD solver contains an APPROXIMATION of the structure.

Details already presented in the previous talks:

MS209A by **Dr. R.Rossi**

"*Advances in the use of simplicial finite elements for flow problems*"

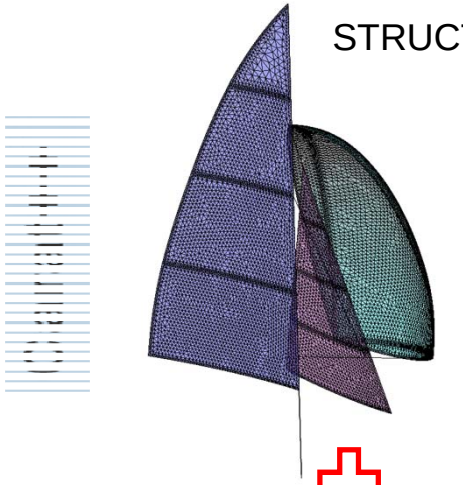
MS042A by: **Dr. P.Ryzhakov**

"An embedded approach for the fluid-structure interaction problems involving light-weight structures"

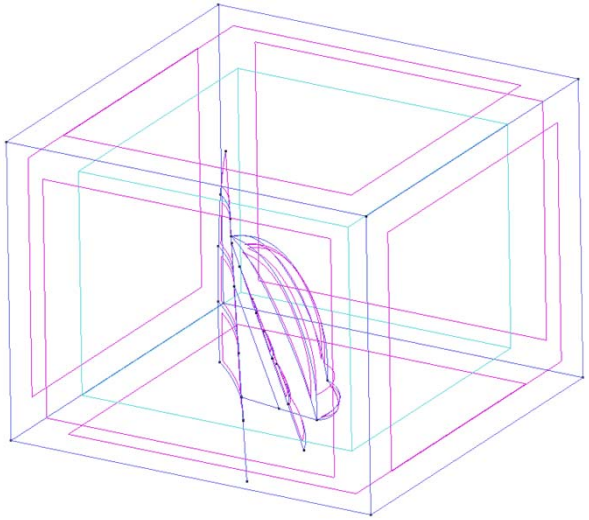
THE VIRTUAL WIND TUNNEL (VWT)

EMBEDDED APPROACH

STRUCTURAL MODEL



FLUID DOMAIN
"CFD BOX"



"CFD BOX" CONTAINING THE INFORMATION OF THE STRUCTURAL GEOMETRY

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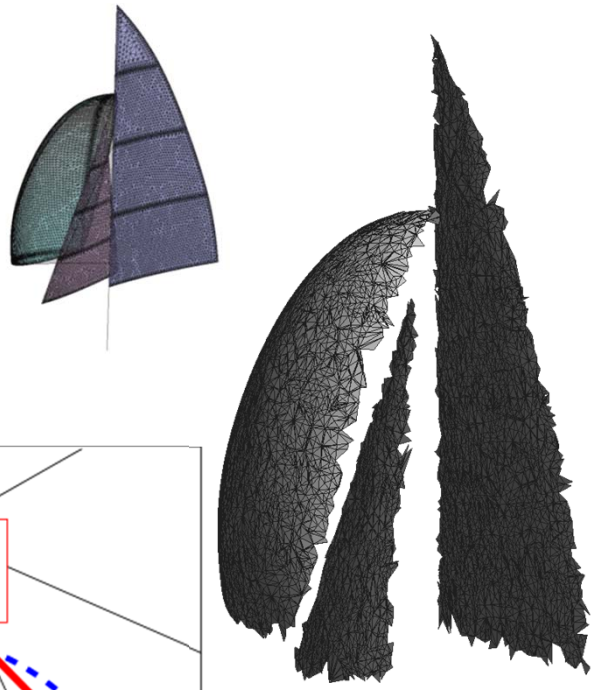
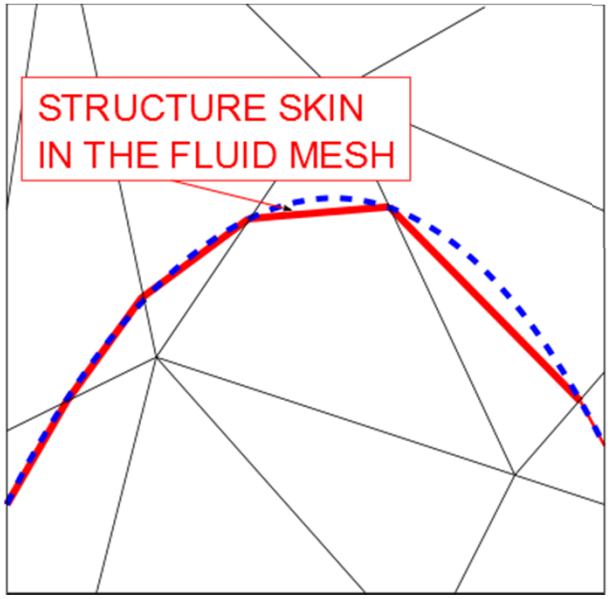
THE VIRTUAL WIND TUNNEL (VWT)

EMBEDDED APPROACH

GEOMETRICAL APPROXIMATION



THE QUALITY OF THE STRUCTURAL EMBEDDED MESH DEPENDS ON THE DIMENSION OF THE MESH OF THE FLUID BOX



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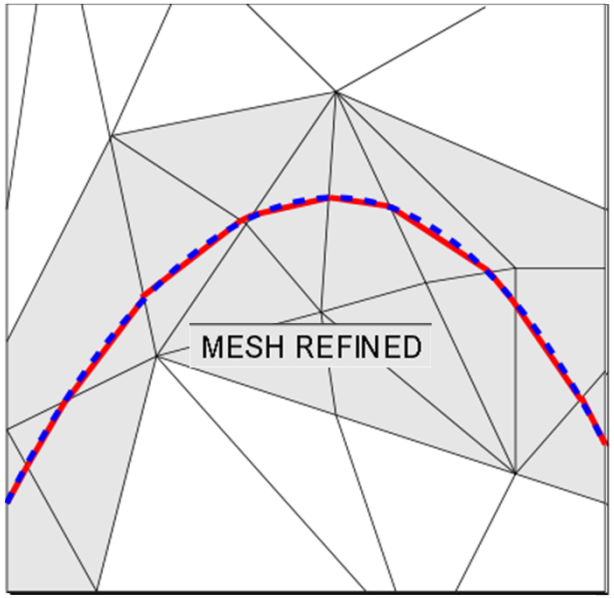
THE VIRTUAL WIND TUNNEL (VWT)

EMBEDDED APPROACH

GEOMETRICAL APPROXIMATION

THE QUALITY OF THE STRUCTURAL EMBEDDED MESH DEPENDS ON THE DIMENSION OF THE MESH OF THE FLUID BOX

ADAPTIVE MESH REFINEMENT NEEDED



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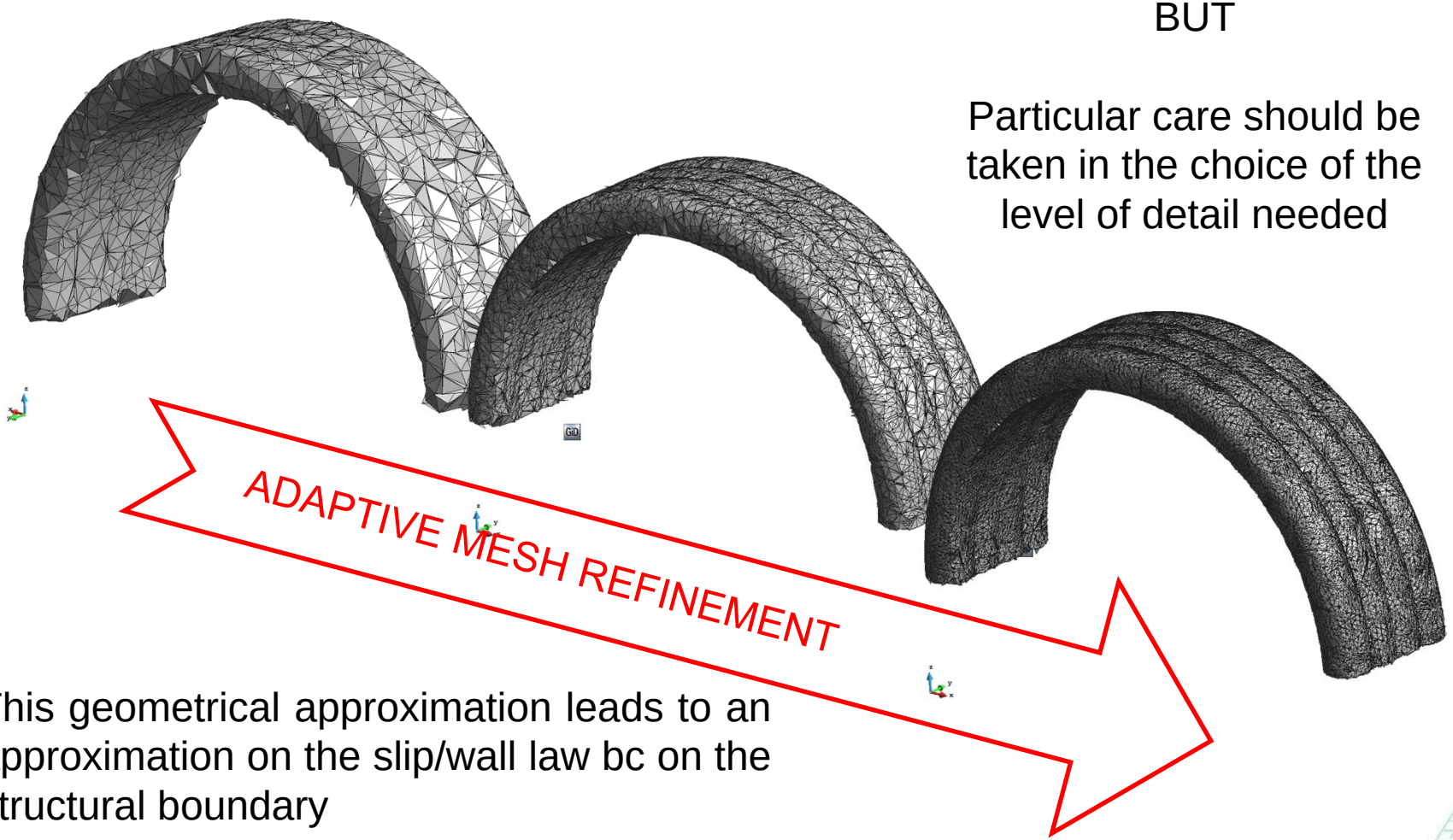
EMBEDDED APPROACH

GEOMETRICAL APPROXIMATION

FAST AND ROBUST

BUT

Particular care should be taken in the choice of the level of detail needed



This geometrical approximation leads to an approximation on the slip/wall law bc on the structural boundary

EMBEDDED APPROACH

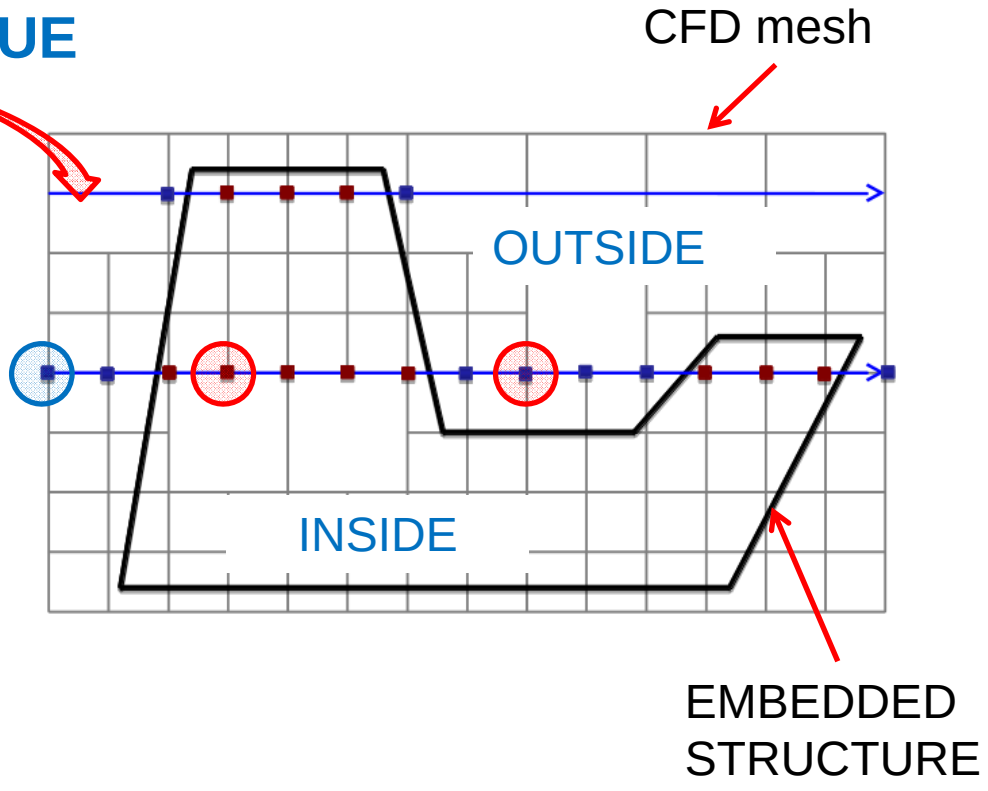
HOW TO DETECT INSIDE AND OUTSIDE NODES?

RAYTRACING TECHNIQUE

Every ray has a certain number of intersections with the structure.

The BOX BOUNDARY nodes are always EXTERIOR nodes.

For each node of the ray count the number of "previous" intersections with the structure.



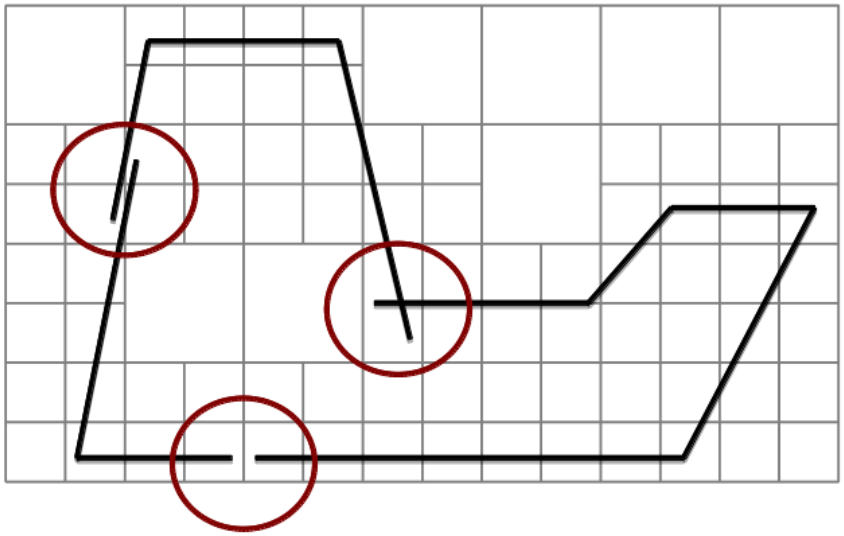
ODD intersection number -> INTERIOR NODE
EVEN intersection number -> EXTERIOR NODE

EMBEDDED APPROACH

HOW TO DETECT INSIDE AND OUTSIDE NODES?

RAYTRACING TECHNIQUE

What to do with overlapping?
With holes?



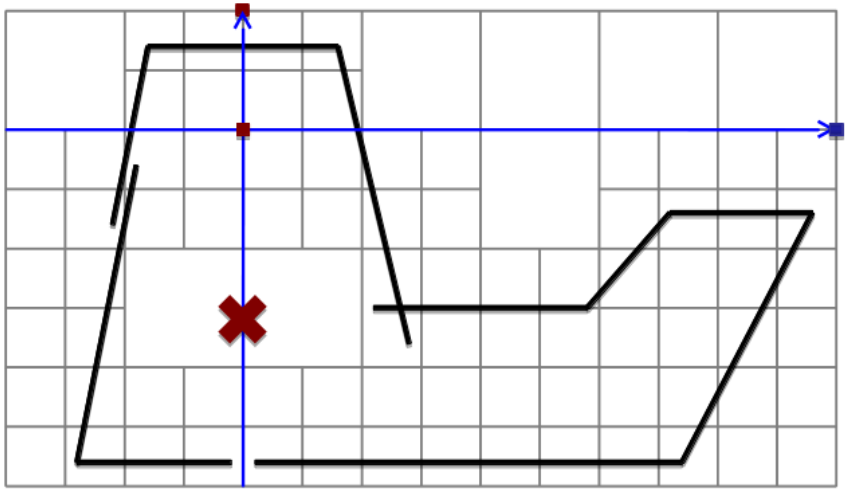
MS208A by: **Dr. P.Dadvand**
"Efficient parallel algorithm for embedded fluid structure interaction with unstructured mesh"

EMBEDDED APPROACH

HOW TO DETECT INSIDE AND OUTSIDE NODES?

RAYTRACING TECHNIQUE

What to do with overlapping?
With holes?



MS208A by: **Dr. P.Dadvand**
"Efficient parallel algorithm for embedded fluid structure interaction with unstructured mesh"

EMBEDDED APPROACH

HOW TO DETECT INSIDE AND OUTSIDE NODES?

RAYTRACING TECHNIQUE

The idea is to use 2 level set indicators to define both the position of the structure and the inside/outside of the inflatable body.

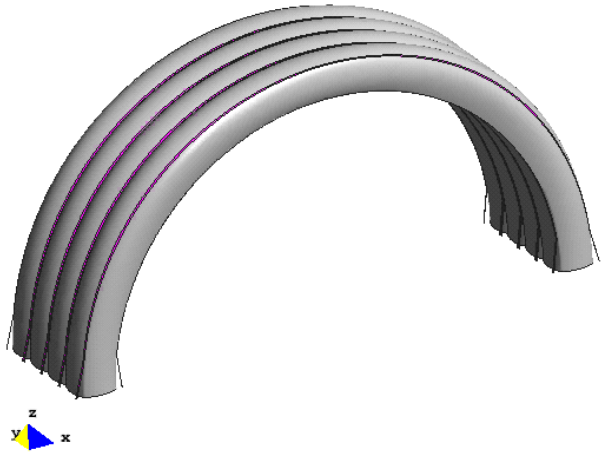
- 1 Define the cut plane locally to each fluid element by providing a discontinuous signed distance function, constructed so that its zero lies on the cut plane
- 2 Define on each node of the fluid mesh a continuous signed distance function, negative within closed domains

EMBEDDED APPROACH

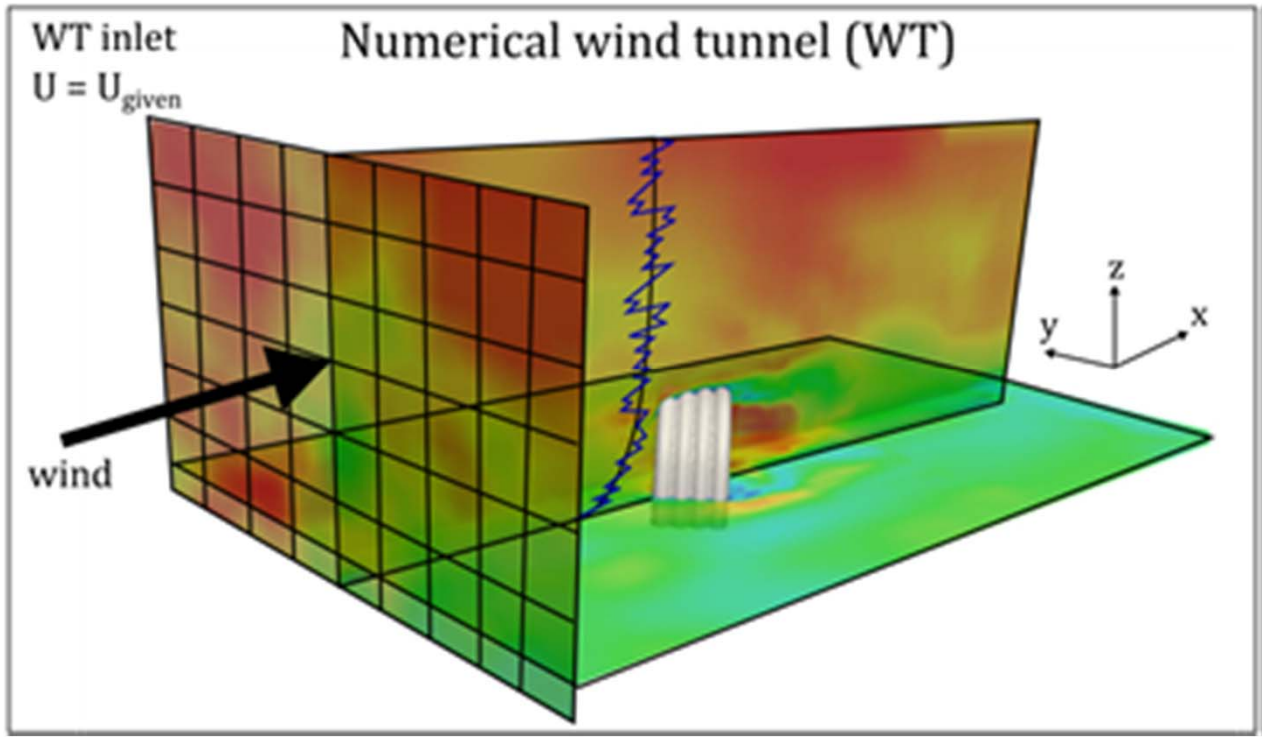
COUPLING ISSUE

In order to ensure the initial convergence of the FSI software, before the activation of the 2 way coupling:

- Stabilization of the inflatable STRUCTURE under internal pressure and self weight only (FSI is off).
- Initial stabilization steps (divergence clearance steps) of the CFD solver (FSI is off).
- One way coupling: calculate the structural deformation due to the fluid flow but zero structural velocity (or displacement) on the Dirichlet boundary



VIRTUAL ATMOSPHERIC BOUNDARY LAYER GENERATION MODULE



ABL FLOW GENERATOR

Details already presented in the previous talks:
MS042A by **Dr. R.Wüchner**
"*Co-simulation of wind -structure interactions*"

COUPLING FLOW CHART

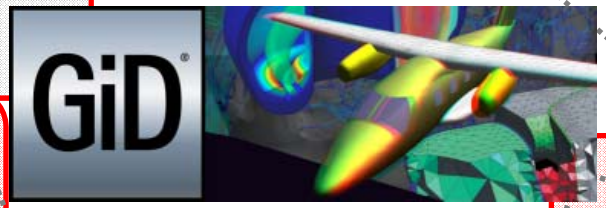
The flow chart of the proposed virtual wind tunnel is the following:

1.Definition of the STRUCTURE
- Identification of the **COUPLING SURFACE**

2.TRANSFERRING to CFD code of the **TRIANGULARIZED COUPLING SURFACE** Construction of the **CFD BOX DOMAIN** and eventually **local refining** in the vicinity of the structure

ABL FLOW GENERATOR

3.Transferring of the **ABL flow** conditions to the CFD inlet



4.SOLVING THE FLUID

5.Mapping the **PRESSURE** forces on the structure;

6.SOLVING THE STRUCTURE

7.Mapping the **DISPLACEMENTS** onto the fluid domain

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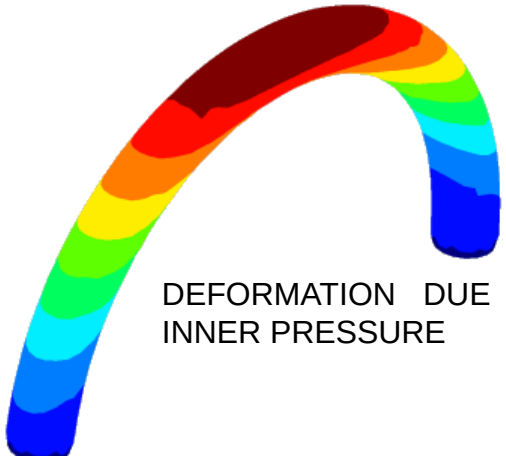
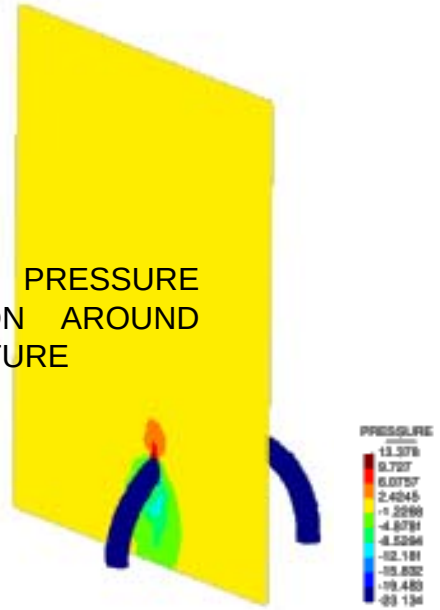
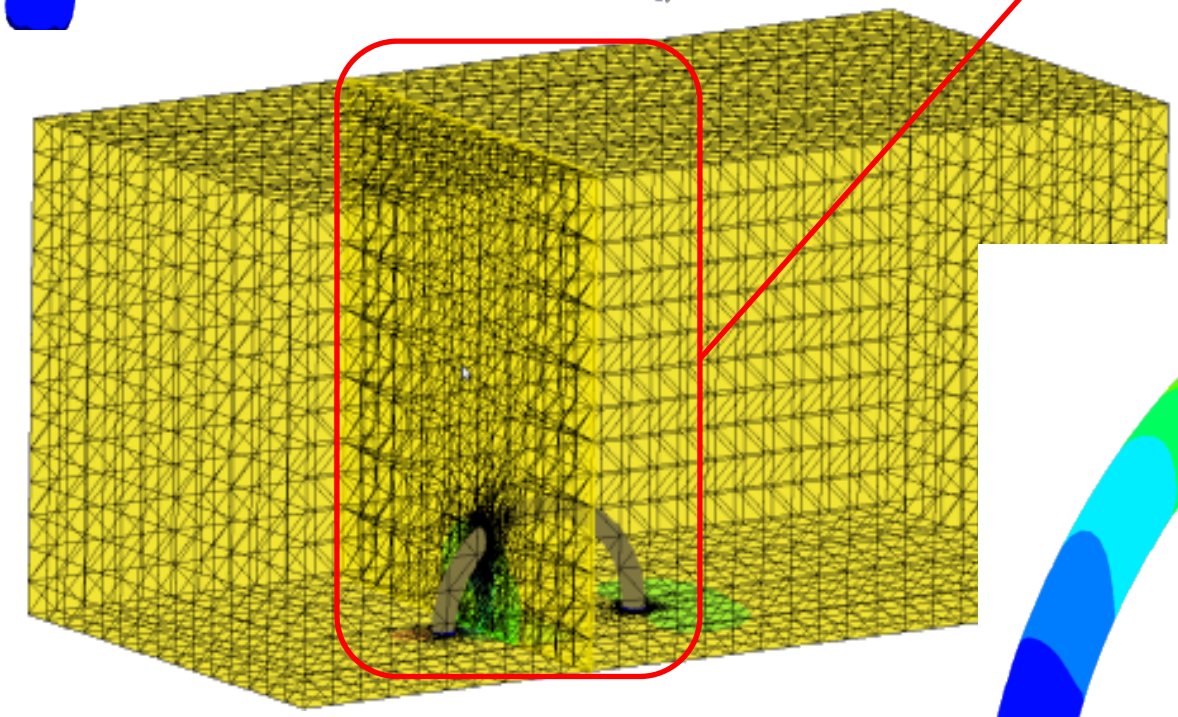
EXAMPLE

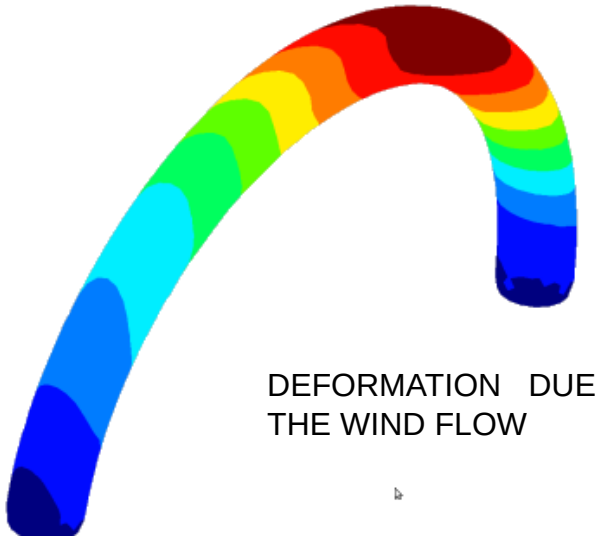


DEFORMATION DUE TO INNER PRESSURE

FLUID PRESSURE DISTRIBUTION AROUND THE STRUCTURE



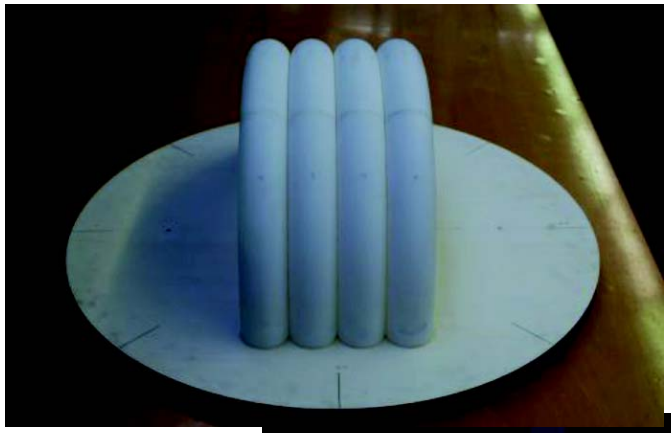


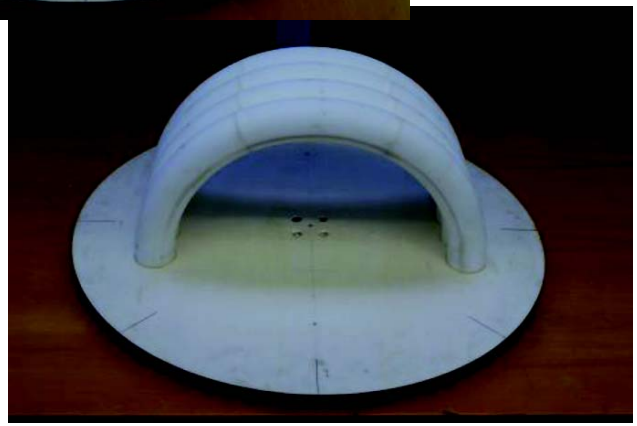


DEFORMATION DUE TO THE WIND FLOW

FUTURE WORK

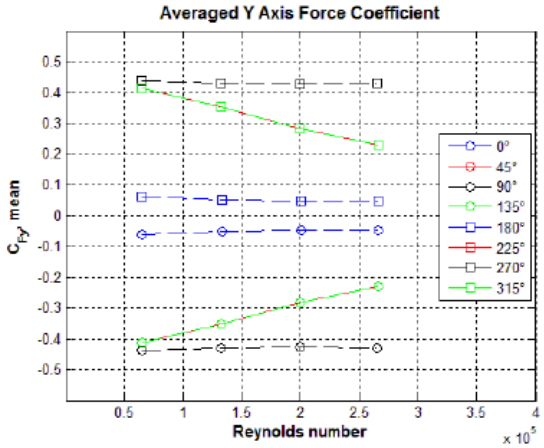
Validation by wind tunnel measurements

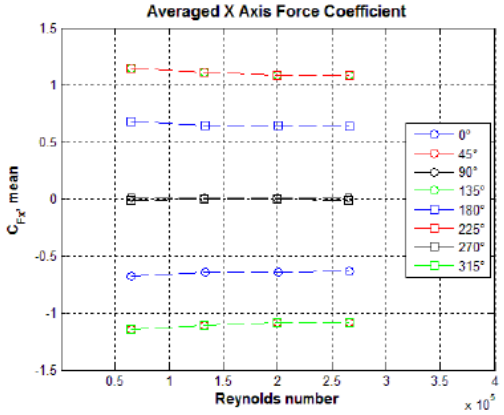




RIGID MODEL

CRIACIV

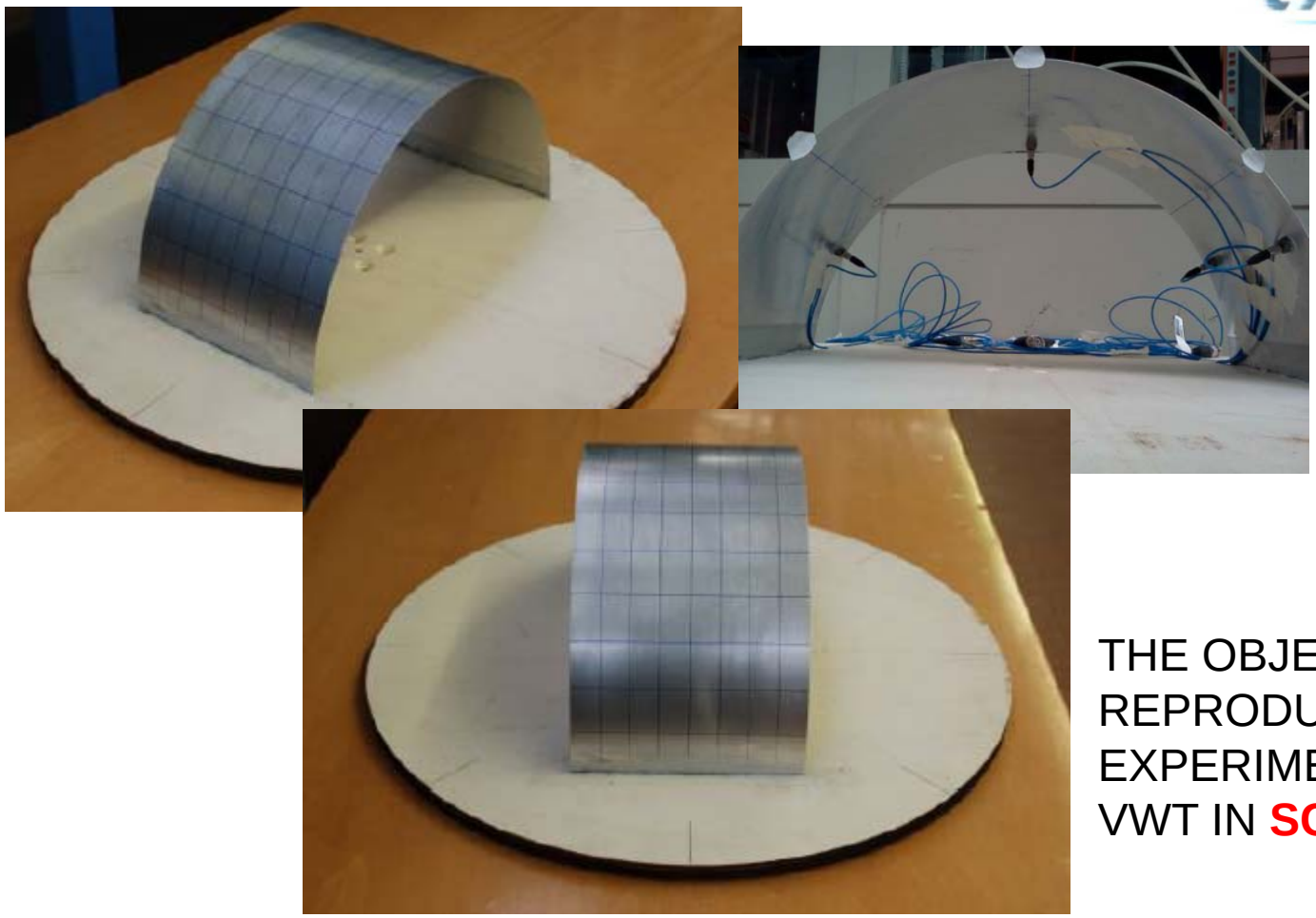




FUTURE WORK

Validation by wind tunnel measurements

FLEXIBLE MODEL



THE OBJECTIVE IS TO REPRODUCE THE EXPERIMENTS WITH THE VWT IN **SCALE 1:1**

CONCLUSIONS

- The strategy adopted to create a Virtual Wind Tunnel has been presented
  - Integration between KRATOS and CARAT++
  - Need for and embedded approach
  - Geometrical approximation
  - Coupling issues

- Validation versus experimental wind tunnel tests in the next months

Thank you for your attention!

antoldt@cimne.upc.edu

www.cimne.com/kratos

www.cimne.com